Cascaded Behavioral Models for Digital Predistortion of Dual-Input Power Amplifiers

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***Abstract*—This paper shows the advantages of using N-stage cascaded (CC) polynomial-based behavioral models over traditional single-stage approaches for linearizing a high-power efficiency dual-input pseudo-Doherty load-modulated balanced amplifier (PD-LMBA). This is achieved through digital predistortion (DPD) linearization applied to 5G signals with a bandwidth of 200 MHz, maintaining a power efficiency close to 50%.**

***Index Terms*—Cascaded behavioral models, digital predistortion, load-modulated balanced power amplifier.**

I. Introduction

The widespread adoption of 4G and 5G new radio (NR) technologies has driven the development of spectrally efficient waveforms, specifically based on orthogonal frequency division multiplexing (OFDM), to accommodate the growing demand for data traffic. However, these signals exhibit a high peak-to-average power ratio (PAPR), becoming a significant challenge for power amplifier (PA) designers. Amplifying signals with high PAPR efficiently while ensuring that signal linearity meets the minimum required standards is crucial. To boost power efficiency along high operational bandwidths and high back-off levels, researchers have proposed dual-input load modulation architectures such as the pseudo-Doherty LMBA [1]. These dual-input architectures allow optimization of the balance between linearity and power efficiency by leveraging the additional flexibility offered by separate inputs. However, digital predistortion (DPD) linearization is still necessary to meet the required linearity specifications.

Classical digital predistortion (DPD) modeling implementations typically use polynomial-based models from the simplified Volterra family (such as memory polynomial (MP) or generalized memory polynomial (GMP)), canonical piecewise-linear (CPWL) functions (including decomposed vector rotation (DVR) [2]), or B-splines (BSP) functions. Moreover, some greedy algorithms have been proposed for an optimal model's coefficients selection according to the degree of relevance (e.g., doubly orthogonal matching pursuit (DOMP) [3]). Recently, cascaded (CC) behavioral models have been explored for DPD purposes, drawing inspiration from the multilayer structure of artificial neural networks (ANNs). These models aim to overcome the limitations of traditional single-stage DPD models by including the possibility to combine the individual features of previously proposed approaches.

This paper presents a comprehensive comparison in terms of DPD linearity performance considering: i) single-stage polynomial-based models; and ii) multistage cascaded polynomial-based DPD models with different coefficient identification approaches. [4].

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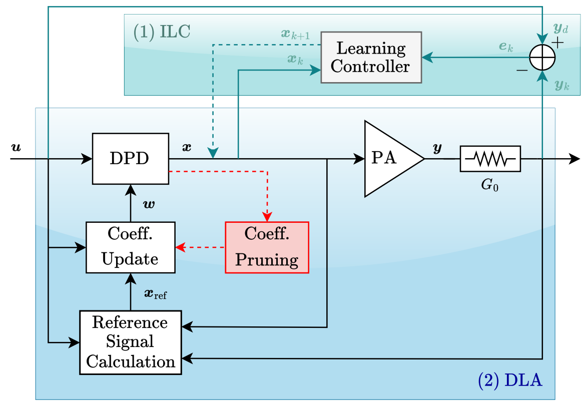

Fig. 1. Block diagram of the iterative learning control (1) and direct learning approach (2) including a model order reduction coefficient pruning block.

II. N-Stage Cascaded DPD Identification

Polynomial-based DPD functions consist of a combination of nonlinear basis functions that are linear with respect to their parameters, enabling parameter estimation through the least squares (LS) method. In single-stage polynomial-based models, the LS approach is the most widely used method. However, when cascaded strategies involve multiple stages, the sequential LS implementation's effectiveness is compromised due to its inability to correct estimation errors that propagate through the flow of the stages.

Therefore, we proposed in [5] the use of gradient descent (GD) as an alternative training method to simultaneously train cascaded stages, considering the impact of each stage on the subsequent ones. Furthermore, we introduced a model order reduction technique with DOMP optimal coefficient selection to decrease the model's complexity while maintaining or enhancing its original performance [4]. Additionally, in order to accelerate the training progress, we proposed using an initial least squares (LS) estimation followed by gradient descent (GD) for further refinement. LS begins the process by computing an initial set of coefficients, which are subsequently refined by GD. The GD method accounts for the propagation of estimation errors across the different stages.

Fig. 1 depicts the procedure for identifying coefficients in a two-stage model: 1) the iterative learning control (ILC) method is used to determine the DPD reference, i.e., the optimal predistorted signal that produces a linear PA output. This signal can serve either as a reference for offline modeling or as an initial condition for coefficient estimation in the subsequent

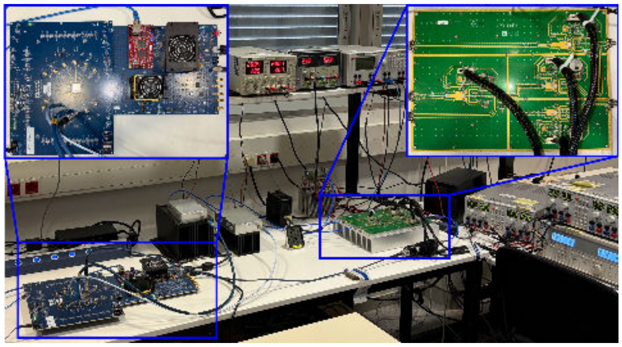

Fig. 2. Experimental setup including the transceiver board and the PD-LMBA.

TABLE I
DPD LINEARIZATION PERFORMANCE USING 200 MHz TEST SIGNAL

DPD Configuration		**Lineariz. Perform. (PAPR = 8 dB)**				
Model	# of Param.	NMSE (dB)	ACPR (dB)	P_{out} (dBm)	Eff. (%)	EVM (%)
w/o DPD	/	-19.80	-27.30	40.4	50.0	5.26
GMP (DOMP)	600	-34.79	-40.62	40.4	49.1	1.89
2-stage CC (LS)	600	-36.88	-43.06	40.3	48.9	1.82
Prun. 6-stage CC	566	-41.34	-47.42	40.6	50.4	1.63

step; 2) the direct learning approach (DLA) process iteratively updates the model's coefficients based on the corrected reference and new signals, enhancing performance and robustness.

III. Experimental Setup and Results

Fig. 2 illustrates the experimental setup used in the lab, with transceiver and control boards (top-left), and the PD-LMBA DUT (top-right). The testbed works with a 5G-NR 64-QAM OFDM signal at 2 GHz with 200 MHz bandwidth, and a PAPR of 8 dB. The PA produces an average output power of 40 dBm with a power efficiency of 50%.

Table I collects the linearization performance without and with different DPD models with near 600 coefficients. The ACPR obtained using the GMP with DOMP optimal feature selection is far from the requirement of ACPR<-45 dB. By implementing a 2-stage cascaded model with LS coefficient identification, we can obtain an ACPR improvement of more than 2 dB, but this is not sufficient. Finally, the 6-stage cascaded model, trained with GD on top LS and incorporating a previous model order reduction technique, achieves an ACPR result of almost -47.5 dB, which represents a notable 7 dB improvement over the GMP model.

IV. Conclusion

This report highlights the superior linearity performance achievable with multistage cascaded DPD models compared to traditional single-stage implementations. Experimental results have shown the linearization of a PD-LMBA using a 5G NR signal with a 200 MHz bandwidth and 8 dB PAPR, achieving 40 dBm output power and 50% power efficiency.

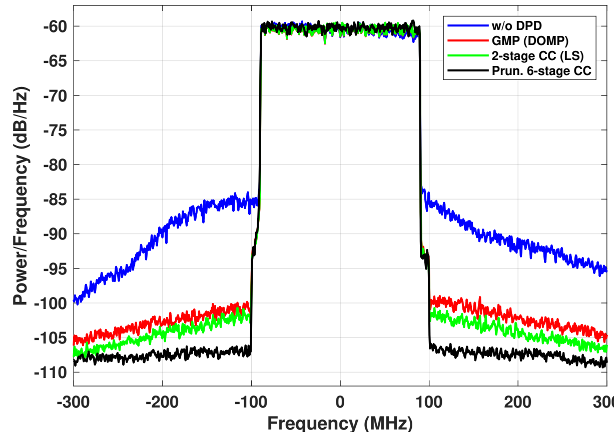

Fig. 3. Output spectra before and after DPD linearization considering different DPD models at near 600 coefficients.

In this context, meeting the ACPR linearity requirements is feasible only with multistage DPD models that employ gradient descent (GD) for coefficient estimation and a prior model order reduction technique.

Acknowledgments and Career Plans

This year, I completed a double bachelor's degree in Telecommunications Systems and Aerospace Systems Engineering. By the end of the year, I will begin a master's degree in Aerospace Science and Technology, with plans to pursue a PhD upon its completion.

I would like to express my gratitude to the IEEE MTT Society for providing opportunities that enable students to engage in research. The IEEE MTT-S Undergraduate Scholarship has allowed me to attend the IEEE MTT-S International Microwave Symposium (IMS) 2024 in Washington and further explore the field of microwave research, which has been an invaluable experience.

Lastly, I extend my thanks to my advisor, Professor Pere L. Gilabert, who has been instrumental in guiding me through my bachelor's degree project and securing this scholarship. I also appreciate my lab colleague, Dr. Wantao Li, for his support and assistance during my introduction to research.

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